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Laser power beaming to extend lives of GSO NiCd satellites*

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ABSTRACT

It is proposed that a ground-based laser can beam power to commercial communication satellites in geosynchronous orbit and reduce battery depth-of-discharge during eclipses. Two laser system designs are presented which have the capability of reducing battery discharge by 100%. Both utilize a steerable beam director, with a mirror diameter of 4 meters in one case and 8 meters in the other. Both also use an adaptive optics unit within the beam train to provide real-time corrections for wavefront distortions caused by atmospheric turbulence. The required system power output is in the range of 100 to 200 kW for a transmitted wavelength just under 900 nm. Laser power beaming can nearly double the remaining lifetime of a satellite that uses NiCd batteries. However, by the time such lasers become available, nearly all NiCd satellites will be replaced by NiH₂ satellites, which stand to benefit much less from power beaming.

1. INTRODUCTION AND BACKGROUND

Considerable savings would result if lifetimes of commercial communications satellites in geosynchronous orbit (GSO) could be extended. The costs of their construction, launch, and orbital transfer are large, so extending their lives would spread these costs over longer periods of time and would make satellite operation more cost effective. This paper promotes laser power beaming from a ground-based laser (GBL) as a technically feasible and practical means of providing lifetime extension for satellites using nickel-cadmium (NiCd) batteries. A reactor-pumped laser (RPL) now being developed by the Department of Energy is one candidate for this application. This laser will be capable of providing high-power at near-infrared wavelengths with long run times,^{1,2} as is required for this power beaming mission, as well as others.

A GSO satellite experiences a yearly cycle consisting of two periods of uninterrupted solar illumination, alternating with two periods of diurnal eclipses. The periods of continuous illumination, which last about 4½ months each, are associated with the solstices. The periods of eclipses, called eclipse seasons, last about 1½ months each and are associated with the equinoxes.³ During any given eclipse season, there will be about 45 diurnal eclipses. The duration of the nth eclipse is approximately given by:

$$T(n) = T(0) \sqrt{1 - (n/23)^2},$$

where n is the eclipse counter, and ranges from -22 at the beginning of the season to +22 at the end. The longest eclipse occurs at the equinox (n = 0) and lasts about 70 minutes, which is the value of T(0).

During an eclipse the satellite's photovoltaic (PV) panels produce essentially no electricity. Batteries in the secondary power system provide all power during this time and undergo discharging until the eclipse is over. The resulting decrease in battery capacity is called depth-of-discharge (DOD), and is measured as a fraction of the rated capacity. The latter is the minimum storage capacity that the battery is designed to provide during its design life, and is measured in amp-hours.

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When an eclipse occurs, the DOD will increase from zero to a peak value that depends upon the eclipse duration, $T(n)$. The peak DOD for the n^{th} eclipse can be approximated by:

$$D_{\text{peak}}(n) = D_{\text{max}} \sqrt{1 - (n/23)^2},$$

where D_{max} equals $D_{\text{peak}}(0)$, the peak DOD at the equinox.⁴ After the eclipse has ended, the DOD returns to zero as the illuminated PV panels recharge the batteries. The value of D_{max} is of particular importance. If it exceeds a critical value, specific to each battery design, then permanent damage to the cells can result. For those NiCd batteries used by GSO satellites, this value is around 70%. In contrast, the nominal range of D_{max} is between 50 and 60%.^{5,6}

2. BATTERY PERFORMANCE MODELING

As the battery DOD reaches a maximum at the end of an eclipse, the battery terminal voltage achieves a minimum called the end-of-discharge (EOD) voltage. Battery performance is a figure of merit which is defined to be the EOD voltage for the most recent discharge event. During its lifetime a battery's EOD voltage will decrease until it falls below the minimum voltage required to provide sufficient power to all subsystems. At this time the battery has reached its end-of-life (EOL) mark for the system it serves and is said to have undergone failure.⁴

Under normal circumstances, the EOD voltage will decrease slightly with each successive discharge-and-recharge cycle. This is referred to as gradual degradation of battery performance. It is a deterministic process that depends upon total operation time and DOD. On rare occasions the terminal voltage will undergo an unexpected and abrupt decrease to zero. This is referred to as sudden degradation and is usually the result of an internal short circuit. It is unpredictable in nature, but the probability of it occurring can be estimated and is a function of operation time and DOD.⁴

COMSAT Laboratory has developed a model for NiCd battery performance using available data bases. The model has a deterministic component to represent gradual degradation of battery performance and a statistical component to represent sudden degradation. Together, these model components provide the predicted EOD voltage, V_{pred} , given by:

$$V_{\text{pred}} = V_{\text{eod}}(T_{\text{total}}, D_{\text{max}}) P_{\text{surv}}(T_{\text{total}}, D_{\text{ave}}).$$

The deterministic model component, V_{eod} , is given by the following general expression which is accurate for a large number of NiCd battery designs:

$$V_{\text{eod}} = C_1 - C_2 \log_{10}(T_{\text{total}}) - C_3 D_{\text{max}}.$$

The three fitting parameters (C_1, C_2, C_3) are used to adapt this expression to a specific NiCd battery design. For the INTELSAT IV-A/COMSTAR NiCd battery, COMSAT found that the values of these parameters are 31.591, 0.39226, and 5.1579, respectively. The statistical model component, P_{surv} , provides the probability that the battery will not have suffered a sudden failure. It was derived using the principles of statistical reliability analysis.⁴

Computer simulations with the COMSAT model were performed for the preparation of this paper, and plots of the results are shown in Figure 1. The vertical axis is the predicted battery performance, V_{pred} , and the horizontal axis is the total operation time, T_{total} , in eclipse seasons. There are plots for values of D_{max} ranging from 20% to 60% in steps of 10%. For the INTELSAT IV-A/COMSTAR NiCd battery design the nominal value of D_{max} is 55%.⁴

Battery EOL occurs when V_{pred} falls below the minimum voltage required to power all subsystems. This minimum is 26 volts for the INTELSAT IV-A/COMSTAR satellite design, and is represented by the dashed line in Figure 1.⁴ Predicted lifetimes can be read from the horizontal axis in Figure 1 for each of the given values of DOD. These results are plotted versus DOD in Figure 2. The following expression represents the best fit to these data:

$$L_{\text{pred}} = L_0 \exp(-k D_{\text{max}}).$$

The coefficient L_0 equals 42.8 eclipse seasons, and is a characteristic time for NiCd performance. The constant k is equal to 1.29 and measures the sensitivity to variations in D_{max} , which is assumed to be expressed as a fraction.

3. EFFECTS OF REDUCTIONS IN DOD

The expression obtained for the predicted lifetime, $L_{\text{pred}}(D_{\text{max}})$, can be used to estimate the lifetime extension obtainable for a given reduction in D_{max} . Such a reduction would result if a GBL system were utilized to provide supplemental illumination during eclipses. Two cases will be considered, life-long reductions and mid-life reductions.

3.1 Life-long reduction in maximum DOD

For a NiCd GSO satellite operating without supplemental illumination during eclipses, let the nominal value of D_{max} be designated by D_1 . The nominal predicted lifetime is therefore $L_1 = L_0 \exp(-k D_1)$. For the same satellite operating with GBL illumination during all eclipses, let the reduced value of D_{max} be designated by D_2 . The predicted lifetime now becomes $L_2 = L_0 \exp(-k D_2)$, which is greater than L_1 . The resulting extension in expected lifetime is $\Delta L = L_2 - L_1$, and the fractional extension is:

$$\Delta L/L_1 = \exp(-k \Delta D) - 1.$$

The change in D_{max} , denoted by $\Delta D = D_2 - D_1$, will always be negative, since only reductions in DOD are being considered. Figure 3 illustrates the results obtained. The solid line represents the nominal battery lifetime as a function of D_{max} . The dashed lines represent the lifetime extensions obtainable with specified life-long reductions in D_{max} .

3.2 Mid-life reduction in maximum DOD

The expected lifetime of a NiCd GSO satellite can also be extended when D_{max} is reduced at some time during mid-life. In this case the NiCd will experience two different operational phases. In the first phase there is no illumination during eclipses, so D_{max} equals the nominal value, designated by D_1 . In the second phase there is GBL illumination during all eclipses, so D_{max} equals the new value, designated by D_2 , which satisfies the condition $D_2 < D_1$.

The duration of phase one is designated by t_1 and is to be specified independently. It is assumed that supplemental illumination is introduced before the nominal EOL occurs, so that $t_1 < L_1$. The duration of phase two is designated by t_2 and will be derived in terms of t_1 . It is assumed that t_2 does not exceed the lifetime resulting from operating the battery at D_2 throughout, so that $t_2 < L_2$.

The total expected lifetime is the sum of the durations of the two phases, that is, $L_{12} = t_1 + t_2$. It can be shown that t_2 can be expressed in terms of t_1 , D_1 , and D_2 as follows:

$$t_2 = (L_1 - t_1) \exp(-k \Delta D) = (L_1 - t_1) (L_2/L_1).$$

Then the total expected lifetime is given by:

$$L_{12} = t_1 [1 - \exp(-k \Delta D)] + L_2,$$

and the extension in battery lifetime, $\Delta L = L_{12} - L_1$, is:

$$\Delta L = (L_1 - t_1) [\exp(-k \Delta D) - 1].$$

Figure 4 illustrates the potential lifetime extensions obtainable for specified reductions in $D_{\max}$. Note that significant extensions are possible, even when the reduction in DOD occurs well into the NiCd battery's nominal lifetime.

4. RELATIONSHIP OF DOD TO SUPPLEMENTAL INTENSITY

The relationship between the intensity of the supplemental illumination and the corresponding reduction in $D_{\max}$ can be estimated for a GSO NiCd satellite. If the illumination is provided only during eclipses, then, to first order, the required relationship is a simple scaling operation with scaling factor:

$$(I_0 - I_{\text{supp}})/I_0.$$

Here I_0 equals the solar constant, whose value is 1370 W/m^2 , and I_{supp} is the intensity of the supplemental illumination. The latter is evaluated in terms of an equivalent solar blackbody spectrum, and is therefore a multiple of I_0 . In this paper it will be assumed that $I_{\text{supp}} \leq I_0$.

The scaling factor is used to relate the DOD occurring with supplemental illumination to the nominal value of DOD. Recall that $D_{\text{peak}}(n)$ is the nominal peak DOD for the n^{th} eclipse. If $D_{\text{peak}}^*(n)$ is the value with supplemental illumination, then:

$$D_{\text{peak}}^*(n) = D_{\text{peak}}(n) (I_0 - I_{\text{supp}})/I_0.$$

The same scaling operation also applies to $D_{\max}$:

$$D_{\max}^* = D_{\max} (I_0 - I_{\text{supp}})/I_0.$$

The supplemental illumination intensity can be converted to its monochromatic equivalent, given the wavelength of the laser beam incident upon the PV panels. This step requires estimates of PV conversion efficiencies for both spectra, solar blackbody and monochromatic. The efficiencies depend upon the design and composition of the PV cells being used, as well as their degree of radiation damage.

The GSO satellite in question is assumed to be of "mature" design and fairly close to EOL. Such satellites have cells derived from the "older" silicon-cell technology. Their conversion efficiencies with sunlight are initially around 15% and decrease by about 3% per year. Here the solar conversion efficiency is taken to be 12%, corresponding to seven years in GSO. Conversion efficiencies with monochromatic illumination are typically greatest, at 18%, for wavelengths near 850 nm.⁷ This value will be assumed here, since the transmitted wavelength is assumed to be just under 900 nm. The ratio of the two conversion efficiencies, 18% and 12%, is equal to 1.5, and this factor is used to convert the monochromatic intensity (at 850 nm) to its equivalent solar blackbody intensity. Thus:

$$I_{\text{supp}} = 1.5 I_{\text{mono}} \quad (\lambda \approx 850 \text{ nm}).$$

The reduced DOD can now be rewritten in terms of the laser monochromatic intensity:

$$D_{\max}^* = D_{\max} (I_0 - 1.5 I_{\text{mono}})/I_0 \quad (\lambda \approx 850 \text{ nm}).$$

5. LASER POWER REQUIREMENTS

To obtain 100% reduction in $D_{\max}$ would require supplemental illumination with an equivalent solar blackbody intensity of I_0 during all eclipses. This can be provided by a laser beam having a monochromatic intensity of 915 kW/m^2 at or near 850 nm. Table 1 illustrates two designs for a GBL power-beaming system with a wavelength of just under 900 nm. The atmospheric transmission coefficient is taken to be 80% when the beam is propagating vertically. The slant range to the satellite is assumed to be about 37,300 km and the angle-off-vertical is taken to be about 43° .

For the 8-meter-mirror design, the transmitted power is 60 kW, which is slightly more than is required to achieve a 100% reduction in $D_{\max}$. The maximum monochromatic intensity at the center of the focal spot is 1066 W/m^2 , which is equivalent to sunlight at 1600 W/m^2 or $1.17 I_0$. Over a disk having a diameter of 4.12 m, the average monochromatic intensity is equivalent to I_0 .

For the 4-meter design the transmitted power is 225 kW, which again is slightly more than required to reduce $D_{\max}$ by 100%. The maximum monochromatic intensity at the center of the spot is 1000 W/m^2 , which is equivalent to sunlight at 1500 W/m^2 or $1.09 I_0$. Over a disk having a diameter of 6.38 m, the average monochromatic intensity is equivalent to I_0 .

Table 1. GBL systems to beam power to NiCd satellites in GSO

<u>system parameter</u>	<u>8-m mirror</u>	<u>4-m mirror</u>
transmitted power	60 kW	225 kW
total power to GSO	44.2 kW	166 kW
half-width of beam	3.63 m	7.27 m
maximum intensity:		
monochromatic	1066 W/m^2	1000 W/m^2
solar blackbody	1600 W/m^2	1500 W/m^2
solar blackbody	$1.17 I_0$	$1.09 I_0$
beam diameter for		
average of I_0	4.12 m	6.38 m

6. PROBABILITY OF GBL AVAILABILITY

Using power beaming to extend the lifetime of a given GSO satellite assumes that a GBL system with the required power output is on-line before the satellite's EOL occurs. Table 2 provides qualitative estimates of the probability that a GBL will be available in each year of the current decade. These apply to the laser being developed by DOE, as well as other candidate GBL's. Estimates are provided for medium-power output ($\sim 100 \text{ kW}$) and high-power output ($\sim 1 \text{ MW}$).

Table 2. Probability of GBL Readiness in this Decade

<u>Year</u>	<u>Medium Power</u>	<u>High Power</u>
1993	negligible	negligible
1994	negligible	negligible
1995	very low	negligible
1996	fairly low	negligible
1997	fifty-fifty	very low
1998	fairly high	fairly low
1999	very high	fifty-fifty
2000	near certain	fairly high

Note that neither power level will be available until the second half of the decade, and that the medium-power case has a lead of about two years over the high-power case

7. SATELLITES WITH POTENTIAL FOR LIFETIME EXTENSION

The key to estimating the potential lifetime extension for a GSO satellite is the adjusted end-of-life (EOL) mark. This equals the sum of the predicted EOL mark and the lifetime overage for satellites of the same vintage. The predicted EOL is equal to the satellite activation date, plus the design life, where the latter is generally 10 to 12 years. The lifetime overage is the average time by which satellites of the same vintage have remained active beyond their predicted EOL's.

This is about 2 years for satellites launched in the 1970's and somewhat over 2 years for those launched in the 1980's. In this paper the average lifetime overage is assumed to be 2 years for all satellites.

The general results obtained in Sections 2, 3, and 4 for lifetime extension have been applied to a study group of GSO satellites using NiCd batteries. Each satellite in this group was active in 1992 and was located between 60° West and 160° West, making it visible from the US. These are listed in Table 3, along with their EOL's.⁸⁻¹¹

Table 3. Remaining Adjusted Lifetimes for Active NiCd Satellites

Satellite System	Pred EOL	Adj EOL	RL 92	RL 93	RL 94	RL 95	RL 96	RL 97	RL 98	RL 99	RL 00
Satcom 4	90	92	0	0	0	0	0	0	0	0	0
SBS 4	91	93	1	0	0	0	0	0	0	0	0
Anik C-3	92	94	2	1	0	0	0	0	0	0	0
Anik D-1	92	94	2	1	0	0	0	0	0	0	0
Satcom 5	92	94	2	1	0	0	0	0	0	0	0
Westar IV	92	94	2	1	0	0	0	0	0	0	0
Westar V	92	94	2	1	0	0	0	0	0	0	0
Galaxy I	92	94	2	1	0	0	0	0	0	0	0
Galaxy II	92	94	2	1	0	0	0	0	0	0	0
Anik C-2	93	95	3	2	1	0	0	0	0	0	0
Satcom 1R	93	95	3	2	1	0	0	0	0	0	0
Satcom 2R	93	95	3	2	1	0	0	0	0	0	0
Telstar 301	93	95	3	2	1	0	0	0	0	0	0
Galaxy III	93	95	3	2	1	0	0	0	0	0	0
Telstar 302	94	96	4	3	2	1	0	0	0	0	0
Anik C-1	95	97	5	4	3	2	1	0	0	0	0
Brazilsat 1	95	97	5	4	3	2	1	0	0	0	0
Morelos 1	95	97	5	4	3	2	1	0	0	0	0
Morelos 2	95	97	5	4	3	2	1	0	0	0	0
Telstar 303	95	97	5	4	3	2	1	0	0	0	0
Anik D-2	96	98	6	5	4	3	2	1	0	0	0
Brazilsat 2	96	98	6	5	4	3	2	1	0	0	0
SBS 5	98	00	8	7	6	5	4	3	2	1	0

The table also contains the remaining lifetime (RL) for each satellite in each year from 1992 to 2000. It is apparent that the number of satellites that can benefit from lifetime extension falls off very rapidly. As each is retired, it will most likely be replaced by a satellite using NiH₂ batteries. These stand to benefit far less from laser power beaming, because their lifetimes are so long that they will most likely outlive any other satellite subsystem.

Table 4. Yearly Totals of All Remaining Lifetimes

Year	Total	Medium Power Laser	High Power Laser
1992	79	negligible	negligible
1993	57	negligible	negligible
1994	36	negligible	negligible
1995	22	very low	negligible
1996	13	fairly low	negligible
1997	5	fifty-fifty	very low
1998	2	fairly high	fairly low
1999	1	very high	fifty-fifty
2000	0	near certain	fairly high

Table 4 contains the yearly totals of remaining lifetime, along with probabilities of GBL availability, for each year from 1992 until 2000. For the high-power GBL the break-even date is 1999, at which time there will only be 1 year of total remaining lifetime. This possibility is not promising at all. For the medium-power GBL, however, the break-even date is 1997, when the total remaining lifetime is 5 years.

It is worth noting that there is surely some uncertainty in the GBL availability estimates, enough in fact that the break-even point could be off by as much as one year. Therefore, it is worthwhile to reconsider the medium-power case for the year 1996, in which the total remaining lifetime is about 13 years. This indicates that the potential pay-off for lifetime extension can be considerably enhanced by speeding up the development of the medium-power GBL design.

The last eight satellites in Table 3 (Anik C-1 through SBS 5) will still be active in 1996. Each has a design life of 10 years and an expected lifetime overage of about 2 years. Their estimated remaining lifetimes in 1996 will be 1 year each for the first five (Anik C-1, Brazilsat 1, Morelos 1, Morelos 2, and Telstar 303), 2 years each for Anik D-2 and Brazilsat 2, and 4 years for SBS 5. Figure 4 indicates that a 100% reduction in $D_{\max}$ will approximately double each of these remaining lifetimes, assuming the medium-power GBL is on-line in 1996.

8. CONCLUSION

At present there is significant potential commercial pay-off to be obtained by using laser power beaming to extend the lifetimes of NiCd communication satellites in GSO. The requirements are that the laser system must provide 100-200 kW at a wavelength just under 900 nm for several hours per night. It is estimated that such a laser system will not be available for at least 5 years. Unfortunately, by that time most of the satellites suitable for such lifetime extension will be retired and replaced with satellites using NiH₂ batteries, which do not stand to benefit as much from power beaming.

9. ACKNOWLEDGMENTS

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Figure 1. Effects of DOD and operation time upon NiCd performance (COMSAT NiCd model, Ref. 4).

Figure 2. NiCd end-of-life mark versus maximum depth-of-discharge (life-long).

Figure 3. Estimated extension in battery lifetime for life-long reduction in maximum DOD.

Figure 4. Estimated extension in battery lifetime for mid-life reduction in maximum DOD.

Lifetimes of NiCd satellites in GSO can be extended with GBL power beaming

Requires 100-200 kW of transmitted power at wavelengths just under 900 nm for mirror diameters of 4-8 m

Can approximately double remaining lifetimes of NiCd satellites in GSO

Spreads total cost over longer times and makes operation more cost effective

Laser system must be on-line before 1997 to have an appreciable effect on NiCd satellites

FALCON reactor-pumped laser

OVERVIEW

FALCON
Fusion Activated Laser Concepts

GSO communication satellites experience yearly illumination and power cycles

GEOSATS1

Eclipse durations vary up to a maximum of about 70 minutes at the equinox

Date With Respect to Equinox

Potential commercial pay-off exists but will diminish rapidly in first half of decade

- Significant commercial pay-off would exist if a ground-based RPL were now available
- Requirements are 100-200 kW of transmitted power at a wavelength just under 900 nm with a mirror diameter of 4-8 meters
- Supplemental illumination would need to be provided for several hours each night
- Number of NiCd satellites in GSO will diminish rapidly during first half of decade
- GBL system must be on-line before 1997 for any significant pay-off to be realized
- NiH2 satellites stand to benefit far less because of their very long expected lifetimes

CONCLU

Number of retired satellites will increase substantially during this decade

RETIREE

COMSAT model for battery performance in terms of total operation time and DOD

- Battery performance is terminal voltage after most recent discharge event.
- COMSAT battery model is based upon existing data bases for gradual and sudden failures.

$$V_{pred} = V_{eod}(T_{total}, D_{max}) * P_{surv}(T_{total}, D_{ave})$$

$$V_{eod} = C1 - C2 * \log_{10}(T_{total}) - C3 * D_{max}$$

$$C1 = 31.591, C2 = 0.39226, C3 = 5.1579$$

P_{surv} = probability that battery will not have experienced sudden failure.

NiCd battery performance is dependent upon total operation time and DOD

PERFORM

Battery end-of-life (EOL) mark depends upon maximum depth-of-discharge (life-long)

EOLMARK

Estimated extension in battery lifetime for life-long reduction in maximum DOD

LIFE

Mid-life reduction in maximum DOD can result in lifetime extension

Phase 1:
Only solar
illumination;
nominal $D_{\max}$.

Phase 2:
Supplemental
illumination;
reduced $D_{\max}$.

Activation
of battery

Reduction of
maximum DOD

Retirement
of battery

MIDLIFE

Estimated extension in battery lifetime for mid-life reduction in maximum DOD

MIDDLE

Mid-life reductions in maximum DOD can extend lifetimes of NiCd satellites in GSO

GBL system designs for beaming power to NiCd satellites in GSO

System parameter	8-m mirror	4-m mirror
Transmitted power	60 kW	225 kW
Total power to GSO	44 kW	166 kW
Half-width of beam	3.63 m	7.27 m
Maximum intenisty:		
monochromatic	1066 W/m ²	1000 W/m ²
solar blackbody	1600 W/m ²	1500 W/m ²
solar blackbody	1.17 sun	1.09 sun
Beam diameter for average of 1 sun	4.12 m	6.38 m

DESIGN

Remaining adjusted lifetimes for active NiCd satellites in GSO

Satellite	Pred	Adj	RL	RL	RL	RL	RL	RL	RL	RL	RL
System	EOL	EOL	92	93	94	95	96	97	98	99	00
Satcom 4	90	92	0	0	0	0	0	0	0	0	0
SBS 4	91	93	1	0	0	0	0	0	0	0	0
Anik C-3	92	94	2	1	0	0	0	0	0	0	0
Anik D-1	92	94	2	1	0	0	0	0	0	0	0
Satcom 5	92	94	2	1	0	0	0	0	0	0	0
Westar IV	92	94	2	1	0	0	0	0	0	0	0
Westar V	92	94	2	1	0	0	0	0	0	0	0
Galaxy I	92	94	2	1	0	0	0	0	0	0	0
Galaxy II	92	94	2	1	0	0	0	0	0	0	0
Anik C-2	93	95	3	2	1	0	0	0	0	0	0
Satcom 1R	93	95	3	2	1	0	0	0	0	0	0
Satcom 2R	93	95	3	2	1	0	0	0	0	0	0
Telstar 301	93	95	3	2	1	0	0	0	0	0	0
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Anik C-1	95	97	5	4	3	2	1	0	0	0	0
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Morelos 2	95	97	5	4	3	2	1	0	0	0	0
Telstar 303	95	97	5	4	3	2	1	0	0	0	0
Anik D-2	96	98	6	5	4	3	2	1	0	0	0
Brazilsat 2	96	98	6	5	4	3	2	1	0	0	0
SBS 5	98	00	8	7	6	5	4	3	2	1	0

REMAIN0

Probability of GBL readiness in this decade for medium-power and high-power lasers

Year of decade	Medium power (100's kW)	High power (MW's)
1993	negligible	negligible
1994	negligible	negligible
1995	very low	negligible
1996	fairly low	negligible
1997	fifty-fifty	very low
1998	fairly high	fairly low
1999	very high	fifty-fifty
2000	near certain	fairly high

READY

Yearly totals of remaining lifetimes for NiCd satellites in GSO

Year	Total	Medium power	High power
1992	79	negligible	negligible
1993	57	negligible	negligible
1994	36	negligible	negligible
1995	22	very low	negligible
1996	13	fairly low	negligible
1997	5	fifty-fifty	very low
1998	2	fairly high	fairly low
1999	1	very high	fifty-fifty
2000	0	near certain	fairly high

TOTAL

END

**DATE
FILMED**

3/3/94